A TRANSPORTATION CORRIDOR CASE STUDY FOR MULTI-CRITERIA DECISION ANALYSIS

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ABSTRACT

Roadway planning can become a contentious process. Delays to projects are frequently due to opposition, conflicting interests and differing opinions from stakeholders, resource agencies, planning organizations and others. Due to the many factors affecting the decision making process, the lack of a unique solution and the plurality of opinions, computational tools may support conflict resolution and decision making. Multiple Criteria Decision Analysis (MCDA) offers a framework wherein differing opinions concerning priorities and values may be utilized in a structured process that considers decision factors, ranks factor criteria, and allocates weights to factors so that results reflect the appropriate priority of each factor considered. This paper addresses a GIS-based decision making framework focusing on environmental and early planning needs in a high impacted transportation corridors. It contains an implementation of MCDA called Analytical Hierarchy Process (AHP) into a geospatial analysis framework to support geo-spatial decision making in generating and selecting paths for roadway options. In this approach, each decision factor is represented as a thematic geospatial layer with attributes that express criteria being considered. Pair-wise comparisons of criteria give rise to relative ranking of criteria. For each factor, a numerical weight assigning relative priority in the decision process is computed. The weighted factors are then combined resulting in a cumulative cost surface. This cost surface is used to generate a least-cost path between selected locations on the surface. The AHP method was adapted to the selection of alternative alignments for Interstate-269, which bypasses the metropolitan area of Memphis-TN. The results show close similarity to results generated by use of traditional methods, but were generated using automated approaches. The methodology enables transportation alternatives to be generated in an efficient and systematic manner and enables multiple scenarios to be simultaneously considered in the transportation planning process to facilitate decisions. This procedure allows scientists and researchers to provide methods useful to decision makers and stakeholders in a balanced and rational way that helps to avoid conflict.

INTRODUCTION

Transportation corridor planning involves collaborative decision making among stakeholders who often have conflicting values and objectives. Geographic Information Systems (GIS) are capable of handling massive amounts of data. When coupled with physical or economic models, a GIS may be employed to transform and manipulate spatial and attribute data as needed to express values for evaluation criteria, e.g. the cost of different alternatives, the population exposure to different levels of health risk, and the distribution of road network concentrations in different areas of a city.

Through a case-study approach that focuses the application upon evaluating transportation corridor alignment alternatives, this paper builds upon past efforts to combine GIS and Multi Criteria Decision Analysis (MCDA) capabilities to deliver decision support for selecting among transportation alternatives (Malczewski, 1999). Analytic Hierarchy Process (AHP) is a highly precise tool in planning which can be used in resource allocation, benefit/cost analysis the resolution of critical conflicts, design and optimization. The criteria in planning analysis usually go with intangibles where AHP would also give precise decisions. The high quality GIS maps when combined with MCDA give a sigh of relief to the decision makers. This study proposes the application of AHP which was developed by Saaty (1994) as an eigen value approach involving many GIS layers to identify best suitable attributes of different variables for the proposed I-269 bypassing the metropolitan area of Memphis, TN.

Fundamental methods of AHP are presented, a simplified set of possible spatial layers and attributes are provided to illustrate the application, and detailed implementation of AHP on the subset of spatial layers illustrates the general utility of the application. Results demonstrate how AHP may be easily integrated with remote sensing and spatial information technologies, assist in the generation of a suitable alignment. As suggested by Downs (1994), a major concern addressed by the application is the ability to provide transportation planners with user-friendly and technically supported methods to arrive at decisions that avoid or minimize environmental impacts while delivering vitally needed transportation services that ease congestion.

BACKGROUND – ANALYTICAL HIERARCHY PROCESS

The AHP was introduced by Saaty (1994) is a pair-wise comparison method for multi-criteria decision making. This method employs decision analysis mathematics to determine the priorities of various alternatives using pair-wise comparison of different decision elements with reference to a common criterion. “It can be used to make direct resource allocation, benefit/cost analysis, resolve conflicts, design and optimize systems (Saaty, 1994)”. Decision making in environmental projects have to be compromised for many sociopolitical, environmental, ecological, and economic factors that are to be considered (Kiker et al, 2005). The use of AHP in a variety of decision-making applications is increasing due to the capabilities which are afforded for improved results and resolution of conflict of tangible and intangible factors.

Decomposition

For any form of semi-structured decision making, primary aspects that must be considered include:

- Acknowledging that more than one person is involved in the decision process,
- Different people have different priorities and values,
- Many factors are considered and these factors may be valued in varying ways by different individuals,
- Complex problems being addressed normally do not have a unique and perfectly correct solution.

Fig.1 illustrates the idea of the decomposition using three GIS layers into a hierarchical process.

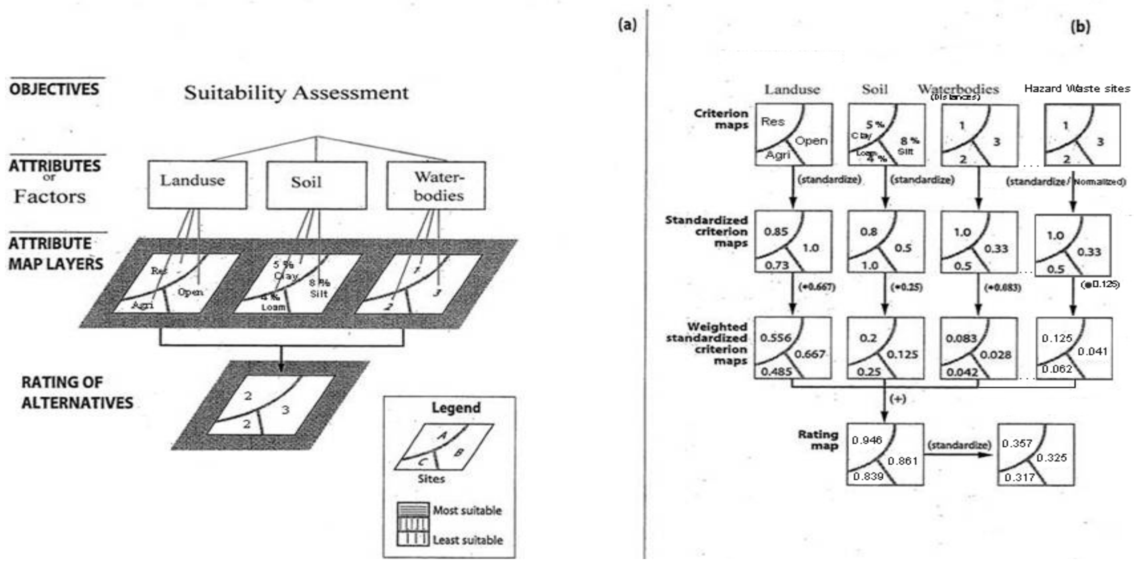

Figure 1. Analytic Hierarchy Process (AHP) Method (a) AHP Procedure;
(b) GIS-based rating of attributes (modified from Malczewski, 1999).

The AHP provides a set of methods for variable value assignment, resolution and standardization of rankings (weights), and selection of global weights for allocating more or less importance to a layer (factor) in arriving at an outcome. To understand how this is accomplished it is necessary to decompose the AHP into a sequence of step-wise tasks, in which the following major task-blocks may be considered:

- Identification of factors and criteria (Lascar 2003),
- Structuring the criteria / attributes (Lascar 2003),
- Judgment of relative importance of the criterions on Saaty's scale and an estimation of consistency ratio (CR) to check the consistency of the judgment made
- Aggregating the map layers according to the decision rule (Malczewski, 1999).

Comparison of Decision Factor and Criteria

AHP is proposed as an equitable method for generating an environmental cost surface for quantification of environmental impacts of selected pathways or to seed the generation of potential transportation alignments based on a least-cost path over a cumulative environmental cost surface. AHP provides a structural basis for quantifying the comparison of decision elements and criteria in a pair-wise fashion. This kind of comparison greatly reduces complexity and enhances simplicity of decision making. "In the GIS database, the attribute-factors are represented as map layers and it contains attribute values for each pixel in raster data" (Kiker et al, 2005).

Regarding the environmental implications of transportation systems, the ranking as proposed by Saaty (1980) is used under the environmental point of view: the higher the weight, the higher the environmental impact. The relative importance of the decision elements or criteria are based on linguistic measures developed by Saaty on a scale of 1 to 9 semantic differential scoring to give relative rating of two criterions. The scale of differential scoring presumes that the row criterion is of equal or greater importance than the column criterion. The reciprocal values (1/3, 1/5, 1/7, or 1/9) have been used where the row criterion is less important than the column criterion.

Table 1. Scale for pair-wise comparison (Saaty 1980).

Intensity of Importance	Definition	Explanation
1	Of equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favors one requirement over another
5	Essential or strong value	Experience strongly favors one requirement over another
7	Very strong value	A requirement is strongly favored and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocals	If requirement one has one of the above numbers assigned to it when compared with requirement second, then second has the reciprocal value when compared with first	

A decision matrix is constructed by using Saaty's scale and factor attributes are compared pair-wise in terms of importance of each criterion/ decision element to that of the next level. Once the pair-wise matrix is made, Saaty's method of eigenvectors / relative weights are calculated by equation [1] and [2] (6).

For a matrix of pair-wise elements:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix}$$

In step-1, sum the values in each column of the pair-wise matrix

$$C_{ij} = \sum_{i=1}^{n} C_{ij} \text{ ....} \qquad \text{.........(} \quad 1 \text{)}$$

In Step-2, divide each element in the matrix by its column total to generate a normalized pair-wise matrix of

$$\begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \qquad X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}} \text{.......... ....(2)}$$

In Step-3, divide the sum of the normalized column of matrix by the number of criteria used (n) to generate weighted matrix of:

$$\begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} \qquad W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n} \text{..(3)}$$

Determining the Consistency Ratio (C_r) involves skill and logic and if the $C_r < 0.10$, then the ratio holds consistency otherwise the ratio is inconsistent and the calculation of numbers requires revision until consistency criteria is attained. First the Consistency Vector is calculated by the following step-1 and step-2 calculations.

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} Cv_{11} \\ Cv_{21} \\ Cv_{31} \end{bmatrix} \text{ ………………. Step – I} \qquad (4)$$

Calculation of Consistency Vector is accomplished by dividing the weighted sum vector with criterion weight in step – II,

$$\begin{aligned} Cv_{11} &= \frac{1}{W_{11}}\left[C_{11}W_{11} + \quad C_{12}W_{21} \quad C_{13}W_{31}\right] \\ Cv_{21} &= \frac{1}{W_{21}}\left[C_{21}W_{11} + \quad C_{22}W_{21} \quad C_{23}W_{31}\right] \text{..........} Step-II \\ Cv_{31} &= \frac{1}{W_{31}}\left[C_{31}W_{11} + \quad C_{32}W_{21} \quad C_{33}W_{31}\right] \end{aligned} \qquad (5)$$

Once the Consistency Vector is calculated, lambda (λ) is calculated by averaging the value of the Consistency Vector. The calculation of the Consistency Index (CI) is based on lambda (λ). CI provides a measure of deviation from consistency. The calculation of CI is based on the observation of λ which is always greater than or equal to the criteria (n) used.

$$CI = \frac{\lambda - n}{n-1} \text{................(6)}$$

Where n = number of criteria used.

RANDOM INCONSISTENCY INDICES (RI) FOR $N = 10$

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Source: Satty (1980).

$$C_r = \frac{CI}{RI} \text{..........................(7)}$$

CASE APPLICATION

Interstate 69 is a 1,600-mile long corridor proposed to connect Canada to Mexico across the Unites States. The overall project is divided into 32 Segments of Independent Utility (SIU) for studies purposes. SIU-9 ranges from Millington-TN to Hernando-MS crossing the metropolitan area of Memphis-TN by reusing some existing roads such as I-55. However, a new I-269 bypassing the Metropolitan Memphis area to the east is being constructed (Fig.2), which our research test area. The study area of this particular paper corresponds to a 25-mile corridor from Hernando-MS to Collierville-TN.

This study is part of Validating Commercial Remote Sensing and Spatial Information Technologies for Streamlining Environmental and Planning Processes in Transportation Projects (http://www.ncrste.msstate.edu/), which is sponsored by the U.S. Department of Transportation – Research and Innovative Technology Application (DOT-RITA).

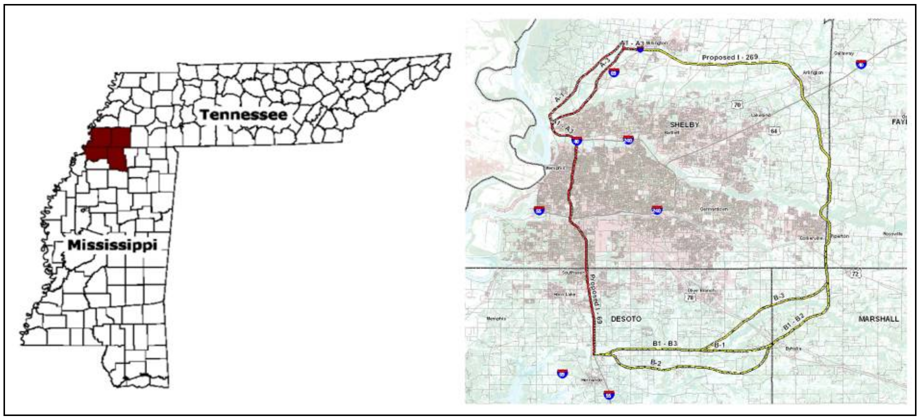

Figure 2. General location of the study area (left) and the proposed I-269 bypassing Memphis at East (right).

Developing the Evaluation Hierarchy with Preliminary Data

In this study, environmental suitability for I-269 is the main concern of the preliminary study; therefore this paper deals with an illustrative example presenting environmental aspects of the decision factors from the author's point of view of assumed pair-wise rankings. The pair-wise rankings are for illustration purposes only, however efforts were made to arrive at rankings that are consistent with typical environmental assessment approaches as suggested in the literature. This case study presents a full implementation of determining appropriate ranks and values based on test case assumptions, but this approach may be easily modified to use rankings and weights provided by key decision makers and stakeholders in the corridor planning process.

This case study is presented in preparation for next steps which will include the implementation of the decision system based on appropriate weights from experts and stakeholders. The case aims at the evaluation of different critical variables using the Saaty's methodology. The synthesis of these variables was done to prioritize environmentally viable alignments for NCRST-SEPP study of I-69. A simple three- tier hierarchy was chosen for decision analysis. After much literature review, a self -explanatory three tier hierarchy was proposed as shown in Fig.3. The second tier in our hierarchy contains decision factors of the preliminary data, of which this paper is concerned mainly on physical factors that describe environmental conditions.

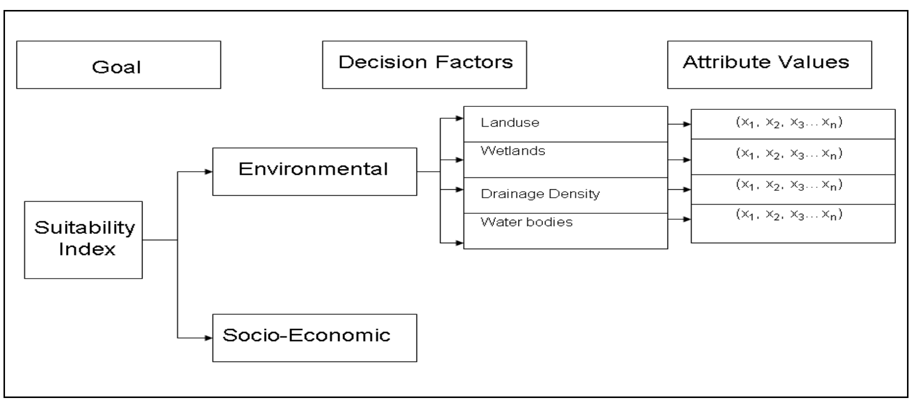

Figure 3. Decision Hierarchy Schema (Modified from Laskar, 2003).

Prioritization and Synthesis

Prioritization is the determination of the relative importance of the map elements which requires rigorous brain-storming among various experts and stakeholders to assign values on a Saaty's scale for a pair-wise comparison of map elements (criteria). Experts are asked to rank the value of a criterion map for a pair-wise matrix on a Saaty's scale. After ranking the pair-wise matrix, vector weights are generated using the equations as explained in the above section. The matrices are created for each criterion / map element in our study with their attributes as rows and columns. In the GIS database, a classified raster map layer is assigned with these vector weights using raster calculator of ArcGIS through map algebra approach.

In the prioritization and synthesis process, experts and stakeholders may be asked to create multiple versions of assigned values, each of which would be based on a written statement describing that scenario. A given scenario could be created to rapidly eliminate non-reuse options for an urban corridor. Similarly, the corridor could be segmented and the non-reuse scenario could be applied to areas in the urban fabric. For rural areas a set of values could be employed that placed high value on prime agricultural land as well as key habitat areas. In practice, a series of scenarios are generated, each of which could be tested to determine the best alignments that are developed using each scenario by utilizing the pair-wise selected set of values associated.

The physical factors selected for this test case include drainage density, distance from urbanized areas, slope classes, and distance from wetlands. Due to the goal of implementing and testing the AHP for environmental studies in transportation corridor, the data used were gathered from National Land Cover Database (NLCD) 2001, National Elevation Dataset (NED-10m) and Memphis Metropolitan Planning Organization. For assigning values, assumptions may be summarized by stating that high selected values equate to high environmental impacts. Thus, the ideal paths would likely be found by a combination of low drainage density, greatest distance from urban areas, flat terrain, and greatest distance from wetlands. On the other hand, high impacts would be derived by a combination of areas with high stream density, low distance to urban areas, low distance to wetlands and moderate to rugged terrain.

Drainage Density

Based on the matrix below, class1 (DD1) is assumed to have a higher density of streams and as a result has high standardized weight. In this study three classes are used: high, moderate and low drainage density. The higher the drainage density, the greater the pair-wise importance, the larger the resultant standardized weight, and consequently the greater the assumed environmental impact for that location. In the GIS database these standardized weights are assigned via a lookup table or recode method to the different classes of drainage density.

$$
\begin{bmatrix}
 & Step-I & & & & & Step-II & & & Step-III & \\
Classes & DD1 & DD2 & DD3 & Classes & Cl1 & Cl2 & Cl3 & /n & Std.Wt \\
DD1 & 1 & 2 & 3 & Cl1 & 0.5455 & 0.5714 & 0.5 & 0.5455+0.5714+0.5 & 0.5389 \\
DD2 & 1/2 & 1 & 2 & Cl2 & 0.2727 & 0.2857 & 0.3333 & 0.2727+0.2857+0.3333 & 0.2972 \\
DD3 & 1/3 & 1/2 & 1 & Cl3 & 0.1818 & 0.1428 & 0.1666 & 0.1818+0.1428+0.1666 & 0.1637 \\
Totals & 1.833 & 3.5 & 6.0 & .. & & & & &
\end{bmatrix}
$$

Determining the Consistency Ratio (C_r)

$$
\begin{bmatrix}
Step-I & & & & & \\
Classes & DD1 & DD2 & DD3 & & Std.Wts \\
DD1 & 1 & 2 & 3 & & 0.5389 \\
DD2 & 1/2 & 1 & 2 & * & 0.2972 \\
DD3 & 1/3 & 1/2 & 1 & & 0.1637
\end{bmatrix}
=
\begin{bmatrix}
Cv \\ 1.6244 \\ 0.89405 \\ 0.4919
\end{bmatrix}
\begin{bmatrix}
Step-II & \\
Cv_1 & 1.6244/0.5389 = 3.0142 \\
Cv_2 & 0.89405/0.2972 = 3.0082 \\
Cv_3 & 0.4919/0.1637 = 3.0048 \\
\lambda = 3.009 & Average-this-column
\end{bmatrix}
$$

$$CI = \frac{3.009-3.0}{2} = 0.0045 \qquad C_r = \frac{0.0045}{0.58} = 0.0077$$

Since our $C_r < 0.1$ the values are consistent.

Slope Classes

Slope classes (SC) are created from the reclassification of NED 10m data. Based on the following matrix SC1 is the highest slope degree (>20%), which has high standardized weight. In this study the higher the slope, the higher the weight. Again, the higher the weight is the more the assumed environmental impact. In GIS database these standardized weights are assigned via a lookup table or recode method to the different classes of slope.

$$
\begin{bmatrix}
 & Step-I & & & & & Step-II & & Step-III & \\
Classes & SC1 & SC2 & SC3 & Classes & Cl1 & Cl2 & Cl3 & /n & Std.Wt \\
SC1 & 1 & 4 & 6 & LD1 & 0.7092 & 0.7504 & 0.6 & 0.7092+0.7504+0.6 & 0.6865 \\
SC2 & 1/4 & 1 & 3 & LD2 & 0.1773 & 0.1876 & 0.3 & 0.1773+0.1876+0.3 & 0.2216 \\
SC3 & 1/6 & 1/3 & 1 & LD3 & 0.1182 & 0.0625 & 0.1 & 0.1182+0.0625+0.1 & 0.0935 \\
Totals & 1.41 & 5.33 & 10.0 & .. & & & & &
\end{bmatrix}
$$

Determining the consistency ratio (C_r)

$$
\begin{bmatrix}
Step-I & & & & & \\
Classes & SC1 & SC2 & SC3 & & Std.Wts \\
SC1 & 1 & 4 & 6 & & 0.6865 \\
SC2 & 1/4 & 1 & 3 & * & 0.2216 \\
SC3 & 1/6 & 1/3 & 1 & & 0.0935
\end{bmatrix}
=
\begin{bmatrix}
Cv \\ 2.1339 \\ 0.6737 \\ 0.2816
\end{bmatrix}
\qquad
\begin{bmatrix}
Step-II & \\
Cv_1 & 2.1339/0.6865 = 3.1083 \\
Cv_2 & 0.6737/0.2216 = 3.0401 \\
Cv_3 & 0.2816/0.0935 = 3.0117 \\
\lambda = 3.0532 & Average-this-column
\end{bmatrix}
$$

$$
CI = \frac{3.0532 - 3.0}{2} = 0.0266 \qquad C_r = \frac{0.0266}{0.58} = 0.045
$$

Since our $C_r < 0.1$ the values are consistent.

Distance from Urbanized Areas

Focusing on the regional scale map for planning purpose, the scenarios were created based on the appropriate use of best-available Federal, State and local vector and raster data. As a bypass, the desired I-269 should maintain certain distance from the Metropolitan Memphis, which in practice means not close from urbanized areas but also not far away. This criterion plays the major importance among the other scenarios during the definition of a macro area to project the corridor.

Using the same analogy from Drainage Density scenario, the shorter the distance, the greater the pair-wise importance is given. Consequently, the greater environmental impact is assessed. Distances from urban areas are included with other categories and are simulated for the purpose of this exploratory test case. The weights are hypothetical, but are based on materials presented in the I-269 FEIS.

$$
\begin{bmatrix}
Step-I & & & & & & Step-II & & & & & Step-III & \\
Classes & UD1 & UD2 & UD3 & UD4 & UD5 & UD1 & UD2 & UD3 & UD4 & UD5 & /n & StdWt \\
UD1 & 1 & 2 & 3 & 4 & 5 & 0.438 & 0.439 & 0.439 & 0.381 & 0.333 & 0.438+0.489+0.439+0.381+0.333 & 0.4162 \\
UD2 & 0.5 & 1 & 2 & 3 & 4 & 0.219 & 0.244 & 0.292 & 0.285 & 0.266 & 0.219+0.244+0.292+0.285+0.266 & 0.2618 \\
UD3 & 0.333 & 0.5 & 1 & 2 & 3 & 0.146 & 0.122 & 0.146 & 0.190 & 0.200 & 0.146+0.122+0.146+0.190+0.200 & 0.1611 \\
UD4 & 0.25 & 0.333 & 0.5 & 1 & 2 & 0.109 & 0.081 & 0.073 & 0.095 & 0.133 & 0.109+0.081+0.073+0.095+0.133 & 0.0986 \\
UD5 & 0.2 & 0.25 & 0.333 & 0.5 & 1 & 0.087 & 0.061 & 0.048 & 0.047 & 0.066 & 0.087+0.061+0.048+0.047+0.066 & 0.0624 \\
Totals & 2.2833 & 4.0833 & 6.8333 & 10.5 & 15 & & & & & & &
\end{bmatrix}
$$

Determining the consistency ratio (C_r)

$$\begin{bmatrix} Step-I & & & & & & & \\ Classes & UD1 & UD2 & UD3 & UD4 & UD5 & & Std.Wts \\ UD1 & 1 & 2 & 3 & 4 & 5 & & 0.4162 \\ UD2 & 0.5 & 1 & 2 & 3 & 4 & & 0.2618 \\ UD3 & 0.3333 & 0.5 & 1 & 2 & 3 & * & 0.1611 \\ UD4 & 0.25 & 0.3333 & 0.5 & 1 & 2 & & 0.0986 \\ UD5 & 0.2 & 0.25 & 0.3333 & 0.5 & 1 & & 0.0624 \end{bmatrix} = \begin{bmatrix} Cv \\ 2.1291 \\ 1.3372 \\ 0.8150 \\ 0.4952 \\ 0.3140 \end{bmatrix} \begin{bmatrix} Step-II & \\ Cv_1 & 2.1291/0.4162 = 5.11 \\ Cv_2 & 1.3372/0.2618 = 5.1080 \\ Cv_3 & 0.8150/0.2618 = 5.0603 \\ Cv_4 & 0.4952/0.0986 = 5.0234 \\ Cv_5 & 0.3140/0.0624 = 5.0345 \\ \lambda = 2.5342 & Average-this-last-column \end{bmatrix}$$

$$CI = \frac{2.5342 - 5.0}{4} = -0.6165 \qquad \mathrm{C_r} = \frac{-0.6165}{1.12} = -0.1233$$

Wetlands - Linear Distance Classes

Wetlands distances used the same analogy of urban distance described before. Wetland linear distance (Wl) classes are created from the straight line distances. Based on the above matrix Wl1 is the shortest distance from the wetlands, which has high standardized weight. Consequently it has higher environmental impact. In GIS database these standardized weights are be assigned to different classes of linear distances of wetlands.

$$\begin{bmatrix} & Step-I & & & & & Step-II & & Step-III & \\ Classes & Wl1 & Wl2 & Wl3 & Classes & Cl1 & Cl2 & Cl3 & /n & Std.Wt \\ Wl1 & 1 & 2 & 3 & Wl1 & 0.5455 & 0.5714 & 0.5 & 0.5455+0.5714+0.5 & 0.5389 \\ Wl2 & 1/2 & 1 & 2 & Wl2 & 0.2727 & 0.2857 & 0.3333 & 0.2727+0.2857+0.3333 & 0.2972 \\ Wl3 & 1/3 & 1/2 & 1 & Wl3 & 0.1818 & 0.1428 & 0.1666 & 0.1818+0.1428+0.1666 & 0.1637 \\ Totals & 1.833 & 3.5 & 6.0 & .. & & & & & \end{bmatrix}$$

Determining the Consistency Ratio (C_r)

$$\begin{bmatrix} Step-I & & & & & \\ Classes & Wl1 & Wl2 & Wl3 & & Std.Wts \\ Wl1 & 1 & 2 & 3 & & 0.5389 \\ Wl2 & 1/2 & 1 & 2 & * & 0.2972 \\ Wl3 & 1/3 & 1/2 & 1 & & 0.1637 \end{bmatrix} = \begin{bmatrix} Cv \\ 1.6244 \\ 0.89405 \\ 0.4919 \end{bmatrix} \begin{bmatrix} Step-II & \\ Cv_1 & 1.6244/0.5389 = 3.0142 \\ Cv_2 & 0.89405/0.2972 = 3.0082 \\ Cv_3 & 0.4919/0.1637 = 3.0048 \\ \lambda = 3.009 & Average-this-column \end{bmatrix}$$

$$CI = \frac{3.009 - 3.0}{2} = 0.0045 \qquad \mathrm{C_r} = \frac{0.0045}{0.58} = 0.0077$$

Again, since our $C_r < 0.1$ the values are consistent.

Determination of Relative Weights Based on Saaty's Scale for the Variables Used

Weights are hypothetical for the different variables Slope Classes (SC), Drainage-Density (DD), Urban-Distance (UD) and Wetlands (WL), but expressed as if they are decisive values of experts and stakeholder's opinion, the authors demonstrates here how the decision matrix could be implemented in transportation planning. In the example shown, a scenario is presented that allocates a very high value to urban distances in determining the cumulative environmental costs. A scenario could be developed that emphasized preservation of open spaces and minimal impacts to streams in the area or to emphasize other physical factors, or reuse existing roads as well.

$$\begin{bmatrix} & Step-I & & & & Step-II & & & & & Step-III & \\ Variables & UD & DD & SC & WL & Variables & UD & DD & SC & WL & /n & Std.Wt \\ UD & 1 & 3 & 4 & 4 & UD & 0.5455 & 0.6207 & 0.444 & 0.5 & 0.5455+0.6207+0.444+0.5 & 0.5275 \\ DD & 1/3 & 1 & 3 & 2 & DD & 0.1818 & 0.2069 & 0.3333 & 0.25 & 0.1818+0.2069+0.3333+0.25 & 0.2430 \\ SC & 1/4 & 1/3 & 1 & 1 & SC & 0.1364 & 0.0689 & 0.1111 & 0.125 & 0.1364+0.0689+0.1111+0.125 & 0.1104 \\ WL & 1/4 & 1/2 & 1 & 1 & WL & 0.1364 & 0.1034 & 0.1111 & 0.125 & 0.1364+0.1034+0.1111+0.125 & 0.1189 \\ Totals & 1.833 & 4.833 & 9.0 & 8.0 & & & & & & & \end{bmatrix}$$

Therefore the resultant standardized weights in GIS database are used as factors to control the equation for the final suitability layer.

0.5275*(UD) + 0.2430*(DD) + 0.1189*(WL) + 0.1104*(SC)………………….. (8)

Determining the Consistency Ratio (C_r)

$$\begin{bmatrix} Step-I & & & & & & \\ Variables & UD & DD & SC & WL & & Std.Wts \\ UD & 1 & 3 & 4 & 4 & & 0.5275 \\ DD & 1/3 & 1 & 3 & 2 & & 0.2430 \\ SC & 1/4 & 1/3 & 1 & 1 & * & 0.11035 \\ WL & 1/4 & 1/2 & 1 & 1 & & 0.1189 \end{bmatrix} = \begin{bmatrix} Cv \\ 2.1735 \\ 0.98768 \\ 0.4421 \\ 0.4826 \end{bmatrix} \begin{bmatrix} Step-II & \\ Cv1 & 2.1735/0.5275 = 4.1204 \\ Cv2 & 0.98768/0.243 = 4.0645 \\ Cv3 & 0.4421/0.11035 = 4.0063 \\ Cv4 & 0.4826/0.1189 = 4.0588 \\ \lambda = 4.0625 & Average-this-column \end{bmatrix}$$

$$CI = \frac{4.0625-4.0}{3} = 0.0208 \qquad C_r = \frac{0.0208}{0.90} = 0.0231$$

The resultant attributes of high weights propose high resistance / cost suitability which means environmentally impacted / affected when aggregated.

RESULTS

Four factors were chosen as explained, of which candidate areas or buffers of suitability are preferentially ranked based on the experts and stakeholder’s opinions. Therefore, a set of attributes / candidate areas has to be specified explicitly. Based on the ranking of candidate areas of each factor, a cost path for each factor / scenario is generated as shown in the Fig.4. Aggregation of these factors / scenario maps is done according to the MCDA so that the best possible alternative is chosen. The criterion / factor / scenario are integrated by using the above equation (8) and the resultant map is shown in Fig.5 and Fig. 6. The performance of the outcome alternative is not only dependent on the quality of the attributes but also characterized by the decision maker’s preferences of attributes.

It is important to note that these are preliminary results used to develop and conduct a test implementation of the MCDM framework. All factors and criteria employed were selected with limited input from experts and stakeholders. However the results present quite similarity with the designed I-269 alignment as used in for the final EIA, reported in USDOT (2006).

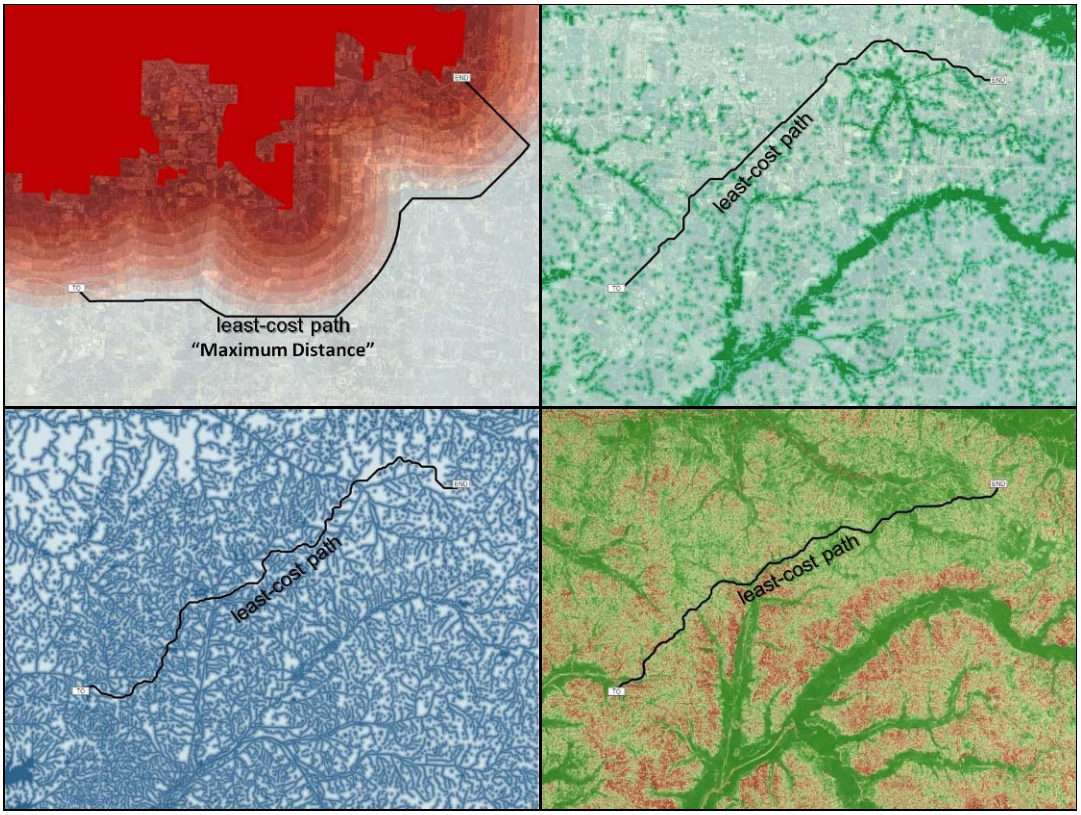

Figure 4. Scenarios generated in this study and lease cost path computed per single scenario: Urbanized areas (top-left), Wetlands (top-right), Drainage Density (bottom-left) and Slope (bottom-right)

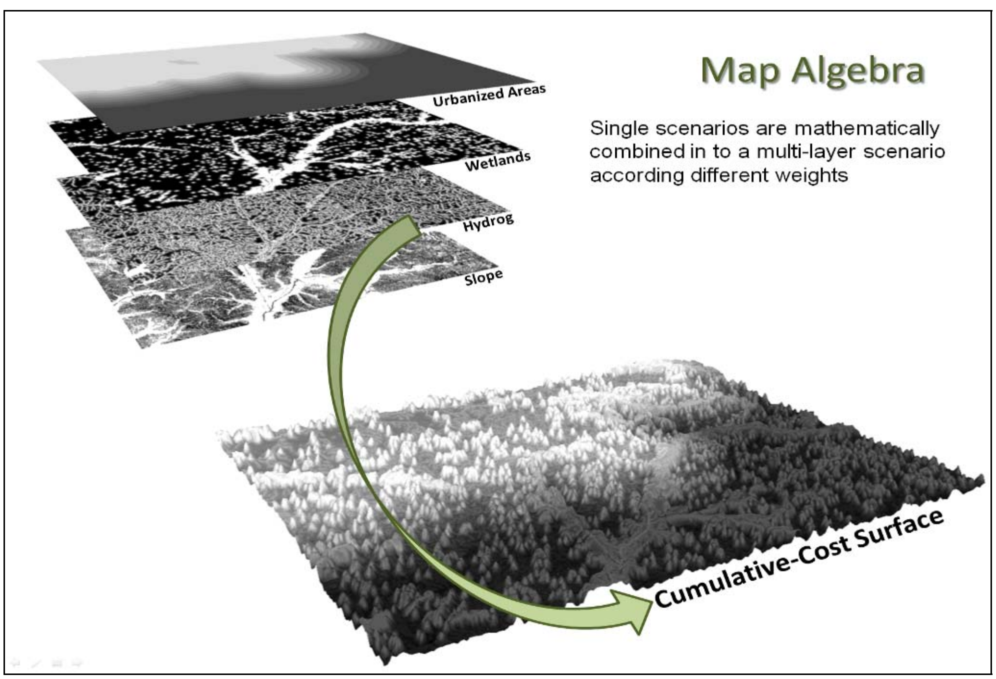

Figure 5. Generation of cumulative cost surface using the model (equation 8).

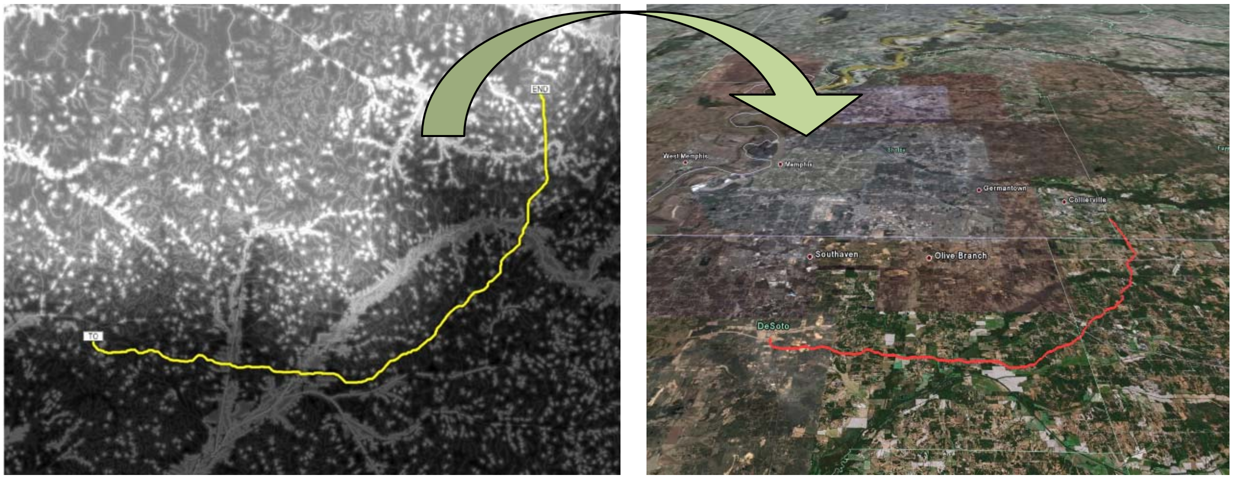

Figure 6. Overall least-cost path projected over the cumulative cost surface (left) and in showing Google Earth.

CONCLUSIONS

In the completed EIS for I-269, alternative routes have been analyzed based on transportation objectives, considering minimization of bad (minimizing the ill effects of) environment and socioeconomic impacts. This paper is focused on testing the technical feasibility of AHP – GIS evaluation, rather than an abstract model for adopting real time multi-objective models for decision analysis. This paper presents a plan and a detailed methodology for effectively adapting AHP with GIS technologies to the task of evaluating or potentially generating a series of least environmentally costly alignments. It served as an initial and efficient exercise of MCDA implementation under GIS domain for the Streamlining Environmental and Planning Process project. A collection of scenarios could be rapidly generated and used to fully explore options that capture the values and opinions of the decision makers and stakeholders for the project.

Although this case study is based on preliminary data, the findings are expected to be readily adapted to the actual area of the project. When implemented, the focus will be placed on selecting values that appropriately capture those expressed in the EIS. The implementation will attempt to show the impacts of each alternative considered in the EIS and will further illustrate how this method could be employed on the selected alignment, but within a selected horizontal distance to horizontally optimize the selected alternative to minimize environmental costs and reduce actual impacts and resultant mitigation requirements.

The presented case study effectively shows that although AHP involves a little bit of work and thoughtful dexterity, pair-wise comparison to select environmental values proved to be efficient and effective. The additive approach chosen for the vector calculations is appropriate because it has the unique quality of preserving the ranks attributed. Preservation of ranks attributed is vital to maintaining the integrity of values selected by stakeholder and experts. Also, it is intuitive that alternatives or variables that receive the same score have equal merit or in this case can be considered to contribute equally to adverse environmental impacts. Combination of GIS capabilities with MCDM techniques involves the phases of intelligence, design and choice (Malczewski, 1999).

Finally, it may be asserted that AHP provides an ideal method of generating scenarios that differ significantly from decision maker or experts, but are in keeping with the opinion of other stakeholders who request consideration of a varying set of relative pair-wise values and who have preferences, opinions, and motivations that deviate significantly from other scenarios. As reported in Piantanakulchai and Saenghao (2003), scenarios generated via implementation of stakeholders' opinions may be efficiently shown to be considered in the EIS process along with other potential and feasible alternatives and included in the collaborative decision process to address opposition and ensure the successful acceptance of study findings. For future development, the existing and future urban developments, socio-economic and cultural aspects as well are going to be considered in the model.

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